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PHYSIOLOGICAL EFFECTS OF INTENSE SOUND

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MCREXD-695-71B

The experiments reported herein were conducted according to the "Guide for Laboratory Animal Facilities and Care," 1965 prepared by the Committee on the Guide for Laboratory Animal Resources, National Academy of Sciences - National Research Council.

The voluntary informed consent of the subjects used in this research was obtained as required by Air Force Regulation 169-8.

16

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ENGINEERING DIVISION
MEMORANDUM REPORT

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SUBJECT: Physiological Effects of Intense Sound

SECTION: Aero Medical Laboratory

SERIAL NO. MCREXD-695-71B

Expenditure Order No. 695-63

A. PURPOSE:

1. To present results obtained in preliminary experiments designed to determine the physiologcial effects of intense sound on man and animals.

B. FACTUAL DATA:

2. Two (2) sound sources have been used in the experiments here reported. The first source was a turbo-jet engine, J-33-9, mounted in an outside test stand. The second source was a special siren, developed for these studies, a mounted in an anechoic chamber (refer to Appendix 1).

3. Severe but thus far temporary losses of hearing have followed exposure of project personnel to intense sound from both sources (Data presented in Appendix 2).

4. When exposed to intense sound fields project personnel have reported the following sensations: (a) marked heating of the skin, (b) strong sensation of vibration in various parts of the body, (c) sensations of muscular weakness and (d) excessive fatigue (see appendix 2).

5. Guinea pigs and rats have been killed when exposed to the intense sound field of the siren for periods as short as eight (8) minutes. The apparent cause of death in these animals was an excessive elevation of the body temperature. Absorption of the acoustic energy in the fur with conversion to heat energy is the apparent cause of the elevated body temperature (see Appendix 3).

Eng. Div. Memo. Report
No. MCREXD-695-71B
24 May 1948

C. CONCLUSIONS:

6. That noise fields sufficiently intense to seriously impair human hearing are produced by turbo-jet power plants currently in use.

7. That the frequency spectrum of the turbo-jet noise field is such that the hearing loss produced in man interferes markedly with the reception and understanding of speech.

8. That sound energy will kill rats and guinea pigs.

9. That the peaks of acoustic energy found in the sound field about a turbo-jet engine are of an order of magnitude comparable with those which have killed guinea pigs and rats exposed to the siren sound field.

10. That the effects here reported have been produced by intense sound fields in the audible range.

11. That the effects here described have usually been attributed to the action of "ultrasonic" frequencies. But since the effects described have been the result of exposure to intense sound in the audible range it is suggested that the important parameter may be intensity rather than frequency.

12. That extensive investigation of the effects of very intense sound of all frequencies is essential to a complete solution of the problem.

D. RECOMMENDATIONS:

13. That the Surgeon, Air Materiel Command, hold those agencies which test and operate turbo-jet engines responsible for:

a. The provision of control-observation rooms in which the sound level is reduced to a safe value. Specifications for the construction and sound treatment of these control-observation rooms to be provided by the Air Installations Section, Air Materiel Command.

b. The reduction to an absolute minimum of time personnel are required to remain in the intense sound field.

Eng. Div. Memo. Report
No. MCREXD-695-71B
24 May 1948

c. The provision of adequate emergency protective devices for the use of personnel who must enter, even for only a brief time, the intense sound field.

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Eng. Div. Memo. Report
No. MCREXD-695- 71B
24 May 1948

Appendix 1

The Sound Sources

Observations have been made of the mechanical and physiological effects of intense sound fields. These intense sound fields have been derived from two (2) sources; (a) the J-33-9 turbo-jet engine and (b) a specially designed siren.

The jet engine was mounted in an outdoor test stand. There were no side or end walls to set up standing waves. The engine stood about seven (7) feet above the ground. This arrangement provides the nearest practical approach to free field conditions for the measurement of a sound field.

The siren was mounted to generate its sound field inside an "anechoic" room. Here again the conditions for free field sound measurements are approached. The siren provided a relatively simple sound field consisting of a fundamental frequency with some harmonics in contrast to the very complex (wide frequency spectrum) sound field of the jet engine.

The overall sound level generated by the turbo-jet engine was found to be a function of turbine revolutions per minute. The sound level increased with increasing r.p.m. and near the engine ranged from about 120 to 150 db above the reference level 0.0002 dynes/cm^2.

The sound level produced by the siren could be varied from a level of about 120 db reference 0.0002 dyne/cm^2 to about 160 db above the reference level.

Appendix 2

Effects of Very Intense Sound on Laboratory Personnel

In the course of measuring the sound fields about jet engines, testing sound generating equipment and making preliminary animal experiments, laboratory personnel have been exposed to very intense sound fields. Several subjective and objective observations have been made of the effects which resulted from these exposures.

Temporary hearing losses have been observed and the magnitude of the losses determined. In some instances personnel exposed themselves to the sound field without protection for the ears to determine quantitatively the hearing loss produced in a given exposure time. In most instances personnel exposed to the sound field wore V-51R ear defenders manufactured by the Mine Safety Appliance Company.

The hearing loss incident to a three and one-quarter (3-1/4) minute exposure, without ear defenders, to the noise near the exhaust cone of a J-33-9 turbo-jet engine is shown in Graph I. This hearing threshold curve was taken twelve (12) minutes after the termination of the exposure. The overall sound level, indicated by a microphone held near the exposed ear, to which the subject was exposed was 142 db above 0.0002 dyne/cm^2. A maximum hearing loss of 25 db occurs at about 1000 cps and the frequency range of the hearing loss is that which one would predict from the known frequency spectrum of the sound field.

The hearing loss which resulted from an exposure of ten (10) minutes, without ear defenders, to the noise near the exhaust cone of the same engine is shown in Graph II. The subject stood 10-12 feet from the end of the tailpipe and approximately twelve (12) inches away from the stream of exhaust gases. The overall sound level, indicated by a microphone held near the exposed ear, was 146 db above 0.0002 dyne/cm^2. The maximum hearing loss is 68 db and is found at a test tone frequency of 1000 cps.

The hearing loss which resulted from exposure to a "synthetic" sound field is shown in Graph III. The sound field was generated by the siren inside the "anechoic" chamber. Standard V-51-R ear defenders, carefully fitted to the subject's ears, were work throughout the exposure. The sound field has been labeled "synthetic" because the exposure consists of several consecutive exposures each to a different fundamental frequency generated by the siren. The frequencies, the exposure times and the sound levels are as follows: (1) 1300 cps for 60 minutes at levels of 130-157 db; (2) 2700 cps, for 28 minutes at levels of 135-157 db. Note the extensive hearing loss between 1500 and 4000 cps. Note also the degree of recovery that occurred in seventeen (17) hours.

Another hearing loss curve which demonstrates the results of exposure to "synthetic" sound fields is shown in Graph IV. The exposure to these sound fields occurred before recovery from the effects of previous experiments was complete. The recovery curve in Graph III shows the hearing threshold at the start of the experiments the results of which are shown in Graph IV. The subject was exposed under the following conditions: (1) 2700 cps at 137 to 162 db for 12 minutes; (2) 650 cps at 137 to 159 db for 26 minutes; (3) 920 cps at 139 to 161 db for 27 minutes; and (4) 4100 cps at 139 to 163 db for 33 minutes. By comparing the initial loss curve from Graph IV with the recovery curve of Graph III it is seen that the hearing loss for all frequencies has increased. Furthermore, there is a marked increase in the hearing loss at low frequencies, which is the result of the exposures to 650 and 920 cps. The hearing loss for 8000 cps is increased. These extensions of the hearing loss could be predicted on the basis of the known frequencies to which the subject was exposed.

The hearing losses (elevations of the curve of hearing threshold) shown in Graphs I through IV are notable for the severity of the loss and for the broad band of frequencies through which the losses extend. Even in the case of a brief exposure, three and one-quarter (3-1/4) minutes, the loss exceeds 20 db over the frequency range 500 to 2000 cps when the subject is exposed to the noise field of a turbo-jet engine (Graph 1). The hearing loss occurs therefore, in the frequency band most significant for the perception and understanding of speech.

An increase of exposure time by a factor of three (3) increases the hearing loss over this critical frequency range by 10 db, extends this loss into the higher frequencies to 3000 cps and more than doubles the maximum loss of hearing at 1000 cps (Graphs I and II). This increase of the hearing loss will significantly decrease the ability to understand human speech. Furthermore, these time intervals are short when compared to the time during which operators of jet engine test cells are regularly exposed to intense sound fields. As the exposure time is increased, the hearing loss will be further increased and the ability to understand the spoken word further impaired.

The effects of exposure to the "synthetic" sound field (Graph III and IV) are significant in that they demonstrate the inadequate protection afforded by currently available ear defenders when the sound fields to which personnel are exposed exceed 145 db. They further show that the effects of two or more exposures are cumulative when insufficient time for complete recovery is allowed between exposures. It is also clearly demonstrated that exposures to essentially single frequencies, one at a time, will produce a hearing loss comparable with that produced by an exposure to a complex noise field containing the same frequency components. Likewise the

frequently observed fact that a pure tone, single frequency, produces very slight or no hearing loss for frequencies below it while producing rather marked hearing losses for frequencies at least an octave above it are confirmed by the experiments described.

The recovery of hearing losses of the magnitudes shown in Graphs III and IV is a slow process. Observe the 17 hour recovery curve shown in Graph III and the 66 hour recovery shown in Graph IV. Complete recovery requires a period of from forty-eight hours to a week or longer depending on the severity of the hearing loss and the response characteristics of the individual subject.

Because of the cumulative effects and the slow recovery it is probable that daily exposures to the sound fields described would result in the production of permanent deafness.

Another observed effect of exposure to very intense sound fields was heating of the skin. When one holds his hand in an intense sound field, i.e., from the siren, with the fingers lightly approximated, heating occurs between the fingers. The degree of heating varies from that which gives rise to a sensation of very slight warmth to that which produces severe pain in a very short time. In an effort to evaluate this heating effect as a function of frequency a series of experiments were performed in which the time required to produce reflex withdrawal of the hand because of pain was measured.

The results of these experiments are shown in Graph V. The time to "pain-withdrawal" as a function of frequency is shown. It is clearly seen that frequencies between 4 and 10 kc, at the intensity levels used, are much more effective than either higher or lower frequencies in producing painful heating. Similar heating occurs (1) between the ears and the head, (2) about an ear defender in the external auditory canal and (3) in the nostrils. A far more extensive investigation, throughout the frequency spectrum, is required to fully elucidate these phenomena.

Another phenomena of interest is the subjective sensation of vibration. At frequencies from about 1500 cps down to about 700 cps there is a sensation of marked vibration of the cranial bones. At certain frequencies in this range the sensation of vibration is so strong from the lower jaw that one reflexly grits his teeth in an effort to stop the vibration. There is also a sensation of vibration combined with air movement in the nasal passages and the bony sinuses. Especially when the mouth is open, a similar sensation is noted in the mouth and pharynx.

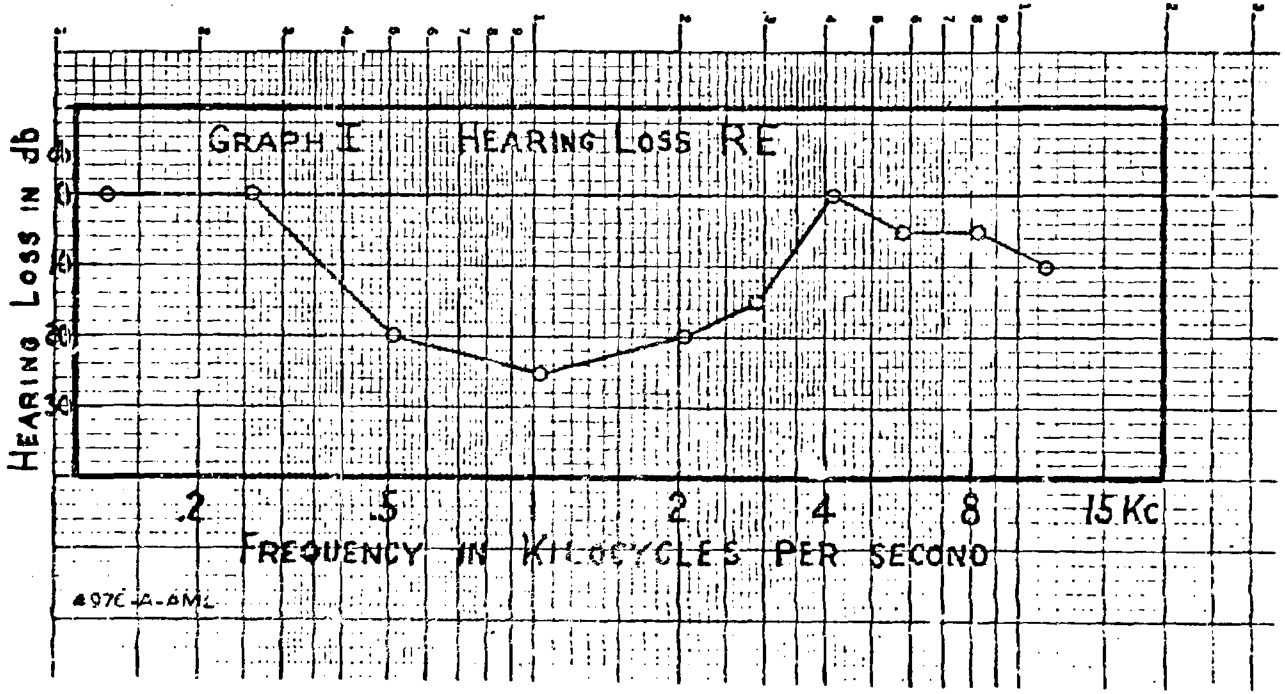
At certain frequencies, which have not been precisely determined, in the range 1500 to 700 cps, the vision may become blurred when one stands in the sound field. Recovery is immediate and complete as soon as one steps out of the sound field.

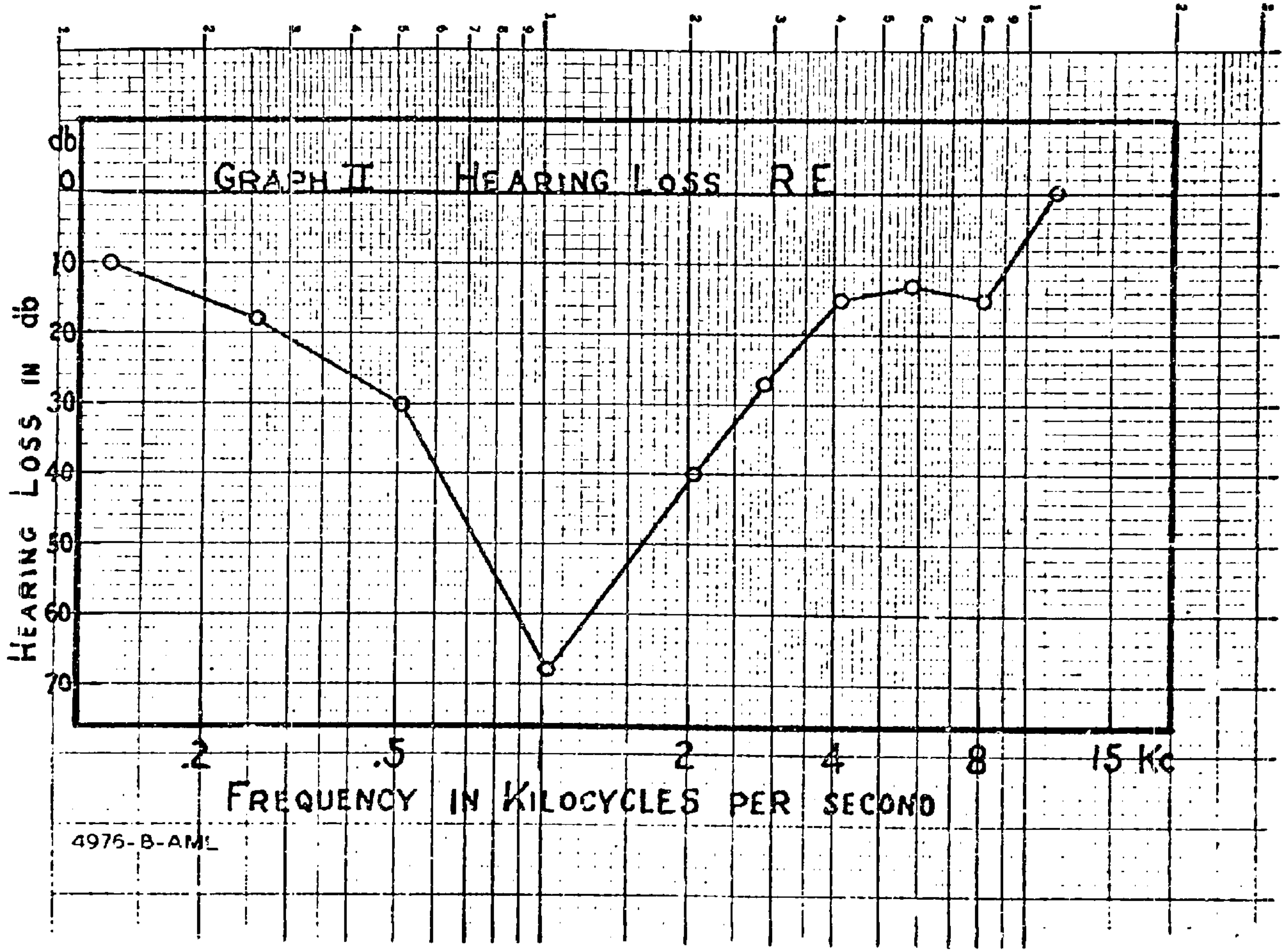
As the frequency of the sound field to which one is exposed is still further decreased the sensations of vibration are felt in the thorax and in single muscles and muscle groups of the arms and legs.

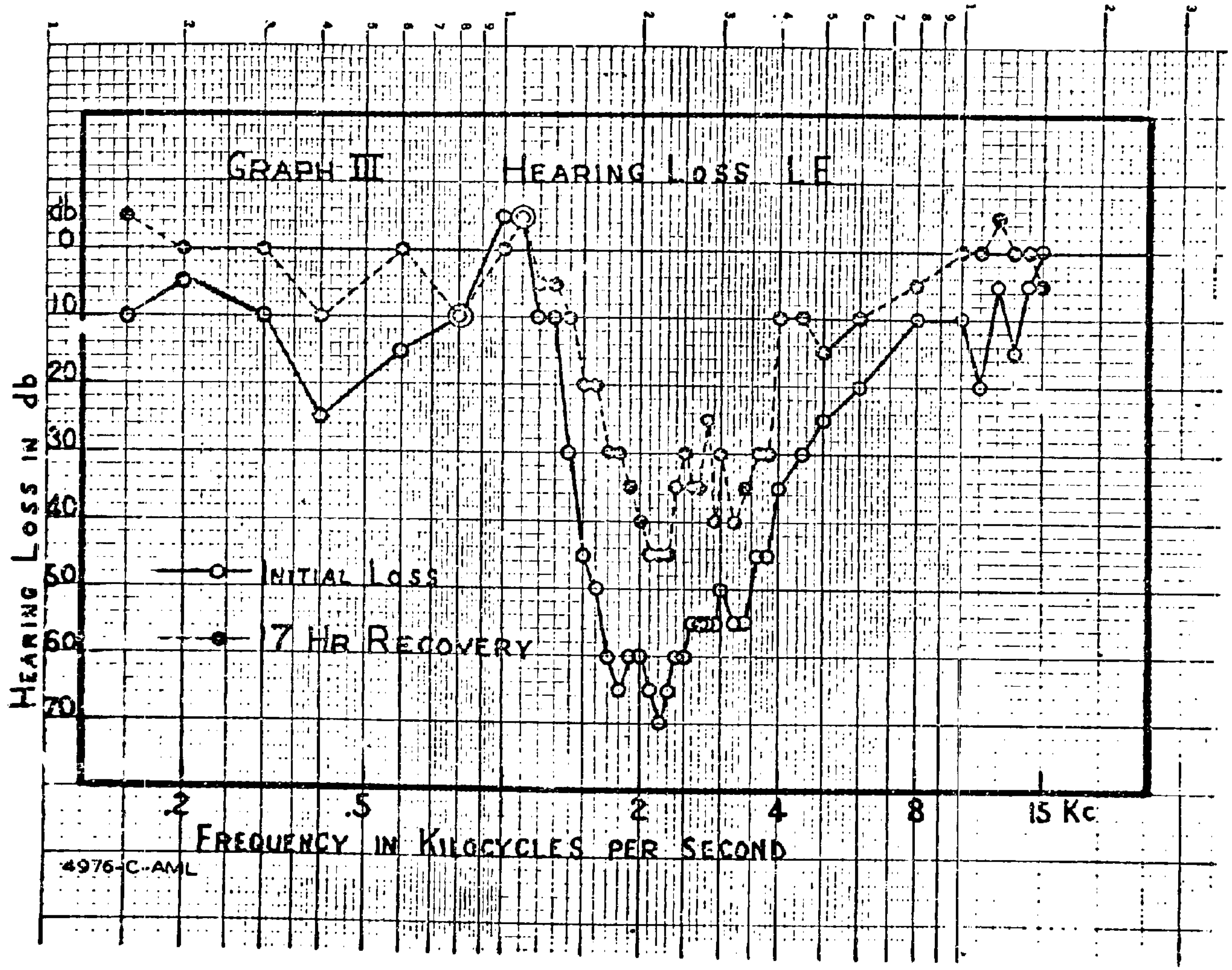
These sensations of vibration, that have been observed in the laboratory at known frequencies and intensities of the sound field, are identical with sensations observed when standing near the stream of exhaust gases from the J-33-9 turbo-jet engine. The vibratory effects produced by the jet engine occurred with the engines in the outside test stands where no walls or other structures were present to cause reflections. It is probable that the phenomena would be more marked in enclosed test stands.

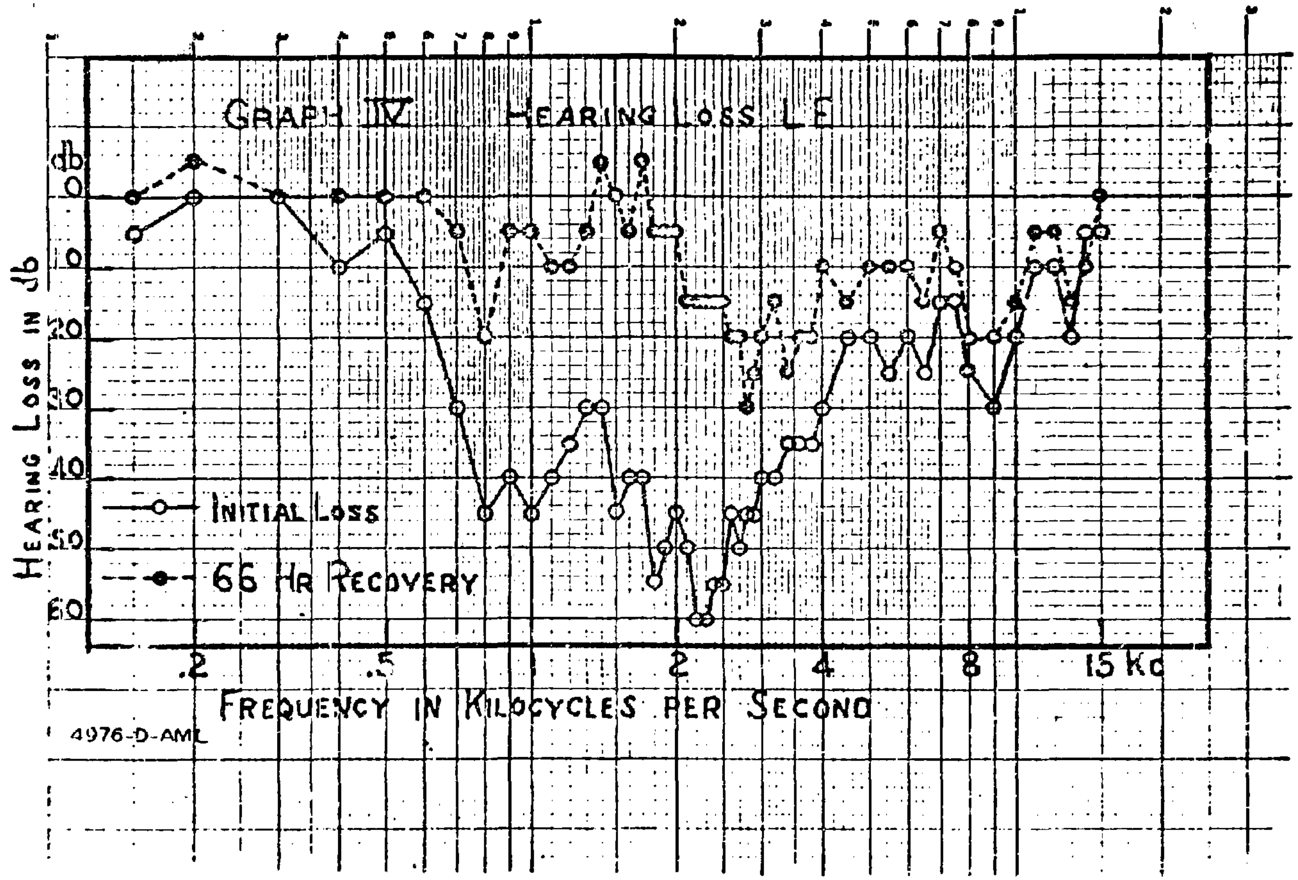
There have been occasions, during exposure to these low frequency sound fields, both in the laboratory and at the jet engine test cells, when personnel have observed a "weakness in the knees" or an apparent general weakening of the body supporting musculature. This sensation is not accompanied by faintness or vertigo and is probably not the result of a true muscular weakness. It would appear to result from an effect on the proprioceptive reflex mechanism since with conscious effort one can maintain the normal erect position usually maintained by reflex mechanisms.

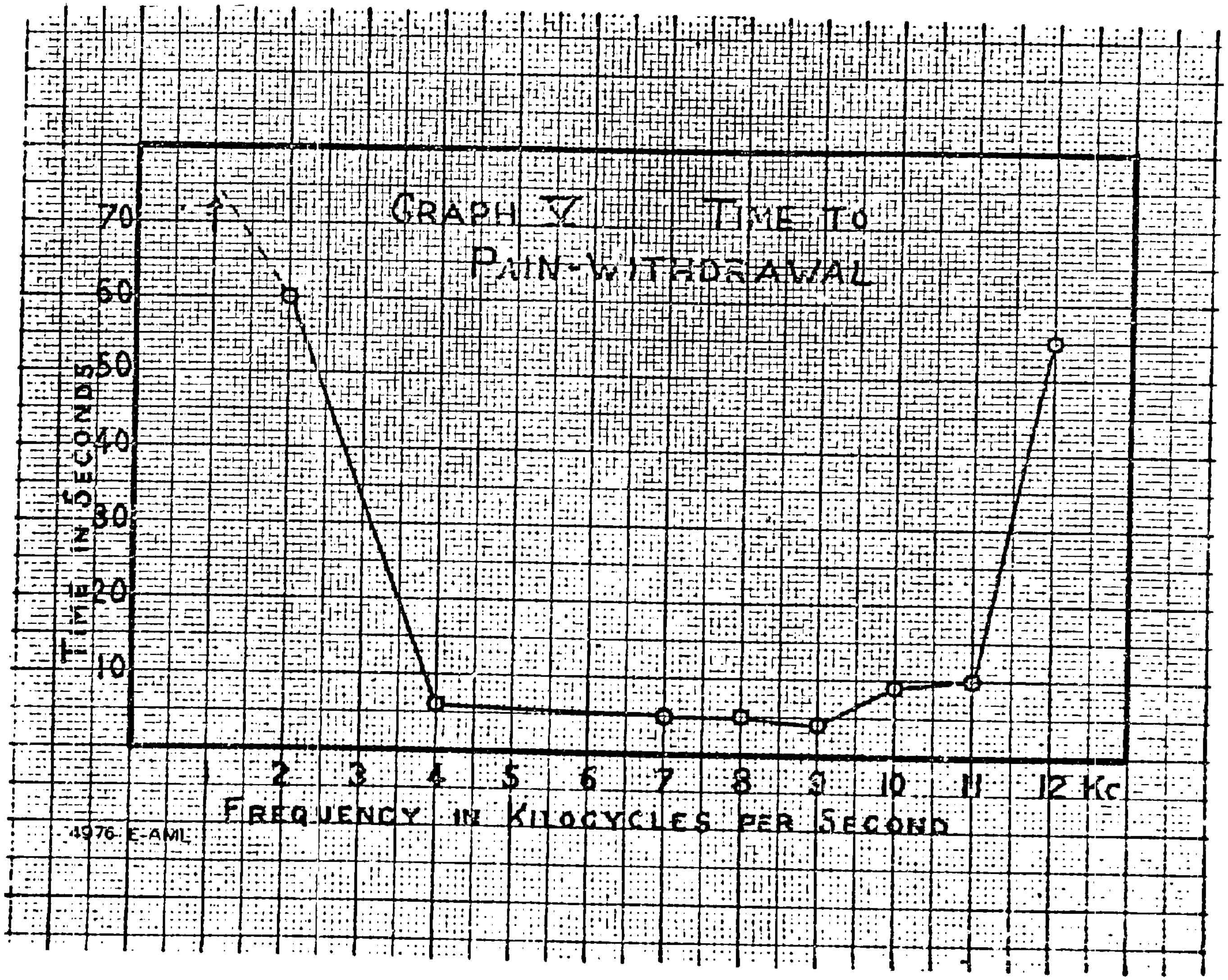
The most important result of these preliminary studies is that they indicate the extensive experimentation yet required in order to determine the possible range and magnitude of effects produced on the human body by intense sound fields.


GRAPH I HEARING LOSS RE
HEARING LOSS IN db
10
20
30
.2
.5
2
4
8
15 Kc
FREQUENCY IN KILOCYCLES PER SECOND
#970-A-AML


GRAPH II HEARING LOSS R E
db
0
10
20
30
40
50
60
70
HEARING LOSS IN db
.2
.5
2
4
8
15 Kc
FREQUENCY IN KILOCYCLES PER SECOND
4976-B-AML


GRAPH III
HEARING LOSS L.E.
HEARING LOSS IN db
db
0
10
20
30
40
50
60
70
INITIAL LOSS
17 HR RECOVERY
.2
.5
2
4
8
15 Kc
FREQUENCY IN KILOCYCLES PER SECOND
4976-C-AML


GRAPH IV HEARING LOSS LE
db
0
10
20
30
40
50
60
HEARING LOSS IN db
INITIAL LOSS
66 HR RECOVERY
.2
.5
2
4
8
15 Kc
FREQUENCY IN KILOCYCLES PER SECOND
4976-D-AML


GRAPH V TIME TO
PAIN-WITHDRAWAL
TIME IN SECONDS
70
60
50
40
30
20
10
2 3 4 5 6 7 8 9 10 11 12 Kc
FREQUENCY IN KILOCYCLES PER SECOND
4976-E-AML

Appendix 3

Exposure of Animals to Very Intense Sound

To observe the general effects of intense sound fields on small animals, rats and guinea pigs have been exposed to sound fields generated by the siren. These animals were "free" in a small cage which permitted movement but restricted them to the central, approximately uniform, portion of the sound field. Fur and rectal temperatures were obtained from time to time by means of thermocouples. The results as a function of frequency are shown in Table I.

Data on Animals Exposed to Intense Sound Fields as Related to the Frequency of the Sound Field

Frequency	Sound Level	Air Temp.	Fur Temp.	Rectal Temp.	Time to death	Animal
1,000	153 db	31°C	50.5°C	42°C	29 Min.	Guinea Pig
1,100	156	32	42	41	45	Rat
3,000	157	30.5	—	43	9	Rat
3,000	155	34	52	42	8	Guinea pig
3,000	156	36	46	44	9	Guinea pig
5,000	156	33	49	51	21	Guinea pig
5,000	157	33	43	63	11	Rat
7,000	157	—	46	44	16	Guinea pig
10,000	154	34	42	46	60 (living)	Guinea pig
12,000	154	35	42.5	44.5	29	Guinea pig

The data of Table I indicate that 3000 cps may be particularly lethal to these animals. Although the sound levels were not identical for all frequencies, the levels at 5000 and 7000 cps were as high as for 3000 cps, yet the animals survived longer. To further examine this point new experiments were carried out in which rats were exposed to frequencies between 2000 and 5000 cps at a fixed sound level. The sound level was 152 db above 0.0002 dyne/cm^2 was held as constant as possible for all frequencies. The results from this series of experiments are shown in Table II.

The Relation of the Frequency of the Sound Field to the Effects on Rats when the Intensity is Held Constant at 152 db.

Frequency	Air Temp.	Fur Temp.	Rectal Temp.	Time to Death
2000	28°C	39°C	39°C	60 min. (living at end of exposure)
3000	30	39	41	20 min.
3500	29	39	42.5	30 min.
4000	26.5	42.5	41	60 min. (living)
5000	28	33	39	60 min. (living)

The sound level here employed was lower than in the previous experiments, nevertheless, the rats were killed at 3000 cps, in a relatively short time (20 minutes). Animals were also killed at 3500 cps. but at all other frequencies they were alive after exposures lasting 60 minutes. One must conclude that for some reason sound at a frequency of 3000 cps is particularly lethal to these animals.

The animals killed were examined carefully to determine the cause of death. It was, of course, known that the body temperature rose to 42° or 43°C during exposure to the sound field. No significant pathology, not associated with increased body temperature, has been found which may have been the cause of death.

Exposure of rats to radiant heat under appropriate conditions has caused death in approximately the same time, has brought about an essentially identical behavior pattern during exposure, and has produced essentially identical pathology at death. Tentatively one must conclude that the absorbtion of acoustic energy from the sound field with conversion to heat and elevation of the body temperature is the primary cause of death. However, one must bear in mind that other factors, not yet observed, may be of equal importance as a lethal factor in intense sound fields.

Gross pathological examination of the animals has revealed hemorrhagic areas in the skin, pulmonary congestion and atelectasis. In some cases there appears to have been small pulmonary hemorrhages although blood has never been observed in the trachea.

Microscopic sections of the lungs show loss of air space or atelectasis, thickening of the alveolar walls and marked engorgement of all blood vessels. In addition there were occasional areas which showed a loss of alveolar tissue, free blood in the alveoli and a leucocytic infiltration around adjacent blood vessels. The leucocytic infiltration was found only in areas where there was free blood in the tissues.